A REVIEW OF ANOPHELINE MOSQUITOES AND MALARIA CONTROL STRATEGIES IN IRIAN JAYA, INDONESIA

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ABSTRAK

TINJAUAN MENGENAI NYAMUK ANOFELES DAN PEMBERANTASAN MALARIA DI IRIAN JAYA, INDONESIA

Bionomik dan peran sebagai vektor keduapuluh dua spesies nyamuk yang ditemukan di Irian Jaya, sudah diulas. Kelompok punctulatus yang semula dilaporkan hanya terdiri dari 5 spesies, saat ini diperkirakan paling sedikit terdiri dari 11 spesies. Kelompok spesies ini adalah vektor malaria yang paling dominan di wilayah Australoasia, meskipun spesies-spesies lain yang ditemukan juga cukup penting. Kunci elektroforesis untuk kelompok punctulatus sudah ada acuannya. Ulasan singkat dan diskusi mengenai strategi pengendalian malaria sudah dilakukan. Program ini umumnya memiliki ciri khas tertentu. Ini ditemukan di negara-negara yang pertumbuhan sosial ekonomi, perangkat pelayanan kesehatan dan tingkat pendidikannya sedang berkembang dan program-program ini difokuskan pada peran serta masyarakat dan strategi pengendalian jentik secara berkesinambungan. Dalam jangka panjang, strategi yang bisa menunjang penurunan populasi vektor di Irian Jaya didiskusikan dengan titik berat pada peran serta masyarakat dan pendidikan, koordinasi pengendalian malaria dengan pengaturan pertanian, meningkatkan ketergantungan pada pengendalian jentik secara berkesinambungan dan melibatkan aparat kesehatan setempat sebagai bagian tak terpisahkan dari program pengendalian malaria di pedesaan.

Diharapkan ulasan ini akan memberikan nilai tambah kepustakaan bagi para entomologiwan yang bekerja di daerah.

INTRODUCTION

Irian Jaya, the eastern most province of Indonesia occupies the western half of the second largest island in the world and is situated between 130 - 141 East Longitude and 0 - 9 South Latitude. The island is divided by the 141st meridian into Papua New Guinea and Irian Jaya. Irian Jaya has a land area of 422,000 square kilometers and shares a 750 kilometer border with Papua New Guinea.
Major islands within the province of Irian Jaya include Biak, Ambai, Waigeo, Gam, and Dolak. The main land mass has a narrow northern coastal range quickly climbing into low hills, a central mountain range climbing as high as 5000 meters, and a broad southern coastal range with innumerable swamps and

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marshes. The province of Irian Jaya is inhabited by an estimated 1.7 million people (1990 census). Major urban centers in Irian Jaya include Jayapura, the provincial capital, Timika, Fakfak, Manokwari, and Merauke. The population is largely rural with an average density of 5 per km^2. Because of the sparse population, Irain Jaya has been targeted by the Indonesian government as a transmigration area in which volunteers from the more densely populated islands of Java, Bali, and Lombok are relocated to recently deforested areas of Irian Jaya. Unfortunately, these areas are often hyperendemic for malaria. The transmigration program in Irian Jaya began during 1983. Since that time approximately 39,000 people have been moved from relatively malaria free areas to hyperendemic areas of Irian Jaya. The act of clear cutting jungle to provide housing and lumber for the transmigrants has unavoidably resulted in a large increase of breeding sites for members of the *Anopheles punctulatus* complex, the primary vectors of malaria in Irian Jaya. This, coupled with the displacement of native Irianese, who often serve as a reservoir for malaria, into the transmigration areas has provided the ideal situation for malaria epidemics; i.e., malaria naive people, receptive mosquito populations, and a reservoir of malaria carriers. Therefore, it is not unexpected that malaria is the leading cause of hospital admissions and the second most common cause of death in the province (Ministry Pub 1995). The mosquitoes primarily responsible for malaria transmission in Irian Jaya are also common in northern Australia, The Solomon Islands, and neighboring Papua New Guinea. Thus, while this is a review of mosquito fauna and malaria control in Irian Jaya, some of the discussion on vector bionomics will draw upon information available from these areas. Discussion on control strategies will draw upon malaria control experiences from around the world.

REVIEW OF ANOPHELINES FOUND IN IRIAN JAYA AND PAPUA NEW GUINEA

In 1966, Steffan[2] provided a checklist of the mosquitoes of the Papuan subregion which included areas as far west as East Timor and Buru Island. He documented 336 species of Culicidae, of which approximately 240 occurred on the island of Irian Jaya and Papua New Guinea (New Guinea). From New Guinea alone a total of 25 anopheline species were documented by Steffan, five of which were then questionable.[2] In their review of anopheline mosquitoes in Netherlands New Guinea (Irian Jaya), Assem and van Dijk[3] documented 20 anopheline mosquito species. These species, plus two more recently identified species are listed in Table 1.

Listed below are brief descriptions of the bionomics of known anopheline species from Irian Jaya.

An. insulaeflorum: Reported from the extreme west (Misool) by Assem and van Dijk.[3] Bonne-Wepster and Swellengrebel reported that larvae prefer shaded breeding places, particularly in the vegetation at the edges of swiftly running small streams and seepages in the jungle.[4] It has been found in swamps, marshes, channels, rivers and rock pools. It is seldom found in rice-fields. It was once found in brackish water at the mouth of a hill stream where it emptied into the sea. The adult is rarely seen, though it has been reported to feed occasionally on man and bovines.

An. palmatus: Similar to the above description.[4] Found in Misool and Vogelkop Peninsula (Manokwari).[3]

Table 1. Anopheline mosquitoes occurring in the Irian Jaya/Papua New Guinea Region

Species	Vector Status	Reference(s) Cited [3,4,12,19,20,34,39]
An. insulaeflorum (Swellengrebel and Swellengrebel de Graaf) 1920	Unknown, rarely feeds on man and is unlikely to be of any significance.	Assem and van Dijk 1958, Rao 1981
An. palmatus (Rodenwaldt) 1926	Unknown.	Bonne-Wepster and Swellengrebel 1953
An. barbumbrosus Strickland and Chowdhury 1927	Unknown.	Bonne-Wepster and Swellengrebel 1953, Rao 1981
An. barbirostris Van del Wulp 1884	Secondary vector. Questionable identification, specimens probably rubbed specimens of *An. bancroftii*.	Assem and van Dijk 1958
An. subpictus Grassi 1899	Primary vector, but only reported from Biak and may no longer be present.	Assem and van Dijk 1958
An. karwari (James) 1903	Primary vector where it occurs, but no longer common if at all present in Irian Jaya, possibly due to residual insecticide spraying.	Assem and van Dijk 1958
An farauti Laveran 1902	Primary vector.	Assem and van Dijk 1958
An. punctulatus Doenitz 1901	Primary vector.	Assem and van Dijk 1958
An. koliensis Owen 1945	Primary vector.	Assem and van Dijk 1958
An. clowi Rozeboom and Knight 1946	Unknown. Rare, only collected from Irian Jaya, near Jayapura.	Bonne-Wepster and Swellengrebel 1953
An. novaguinensis Venhuis 1933	Unknown.	Bonne-Wepster and Swellengrebel 1953, Bruce-Chwatt 1985
An. annulipes Walker 1856	Nonvector? No naturally occurring infected mosquitoes found, rare in Papua New Guinea. Listed as a primary vector by Bruce-Chwatt 1985.	Bonne-Wepster and Swellengrebel 1953, Bruce-Chwatt 1985
An. incognitus Brug 1931	Unknown.	Bonne-Wepster and Swellengrebel 1953, Rao 1981
An. hilli Woodhill and Lee 1944	Secondary vector, found naturally infected in Australia.	Assem and van Dijk 1958
An. meraukensis Venhuis 1932	Unknown.	Bonne-Wepster and Swellengrebel 1953
An. lungae Belkin and Schlosser 1944	Probably nonvector, rarely feeds on humans, breeds in undisturbed jungle.	Belkin 1962
An. longirostris Brug 1928	Nonvector, rarely feeds on humans, breeds in undisturbed jungle.	Belkin 1962
An annulatus De Rook 1929	Unknown, very rare. Only known from type locality.	Bonne-Wepster and Swellengrebel 1953
An. stigmaticus Skuse 1889	Nonvector, does noll bite man in nature.	Bonne-Wepster and Swellengrebel 1953
An. bancroftii Giles 1902	Secondary vector. It may be important in the southern plain on occasion, but rarely found in high numbers or infected.	Assem and van Dijk 1958
An. papuensis Dobrotworsky 1957	Unknown.	Dobrotworsky 1957
An. pseudobarbirostris Ludlow 1902	Unknown, but is rarely found in high numbers.	Bonne-Wepster and Swellengrebel 1953

An. barbumbrosus: The larvae are found in slowly running water, springs, and stagnant water. They may be found in jungle environs, rice fields, open grassy ravines, and in clear streams emerging from jungle shade. Common in Indonesia, particularly the eastern portion.[4] Located in extreme western part of Irian Jaya (Sorong, Tjof Island).[3]

An. barbirostris: A doubtful record exists from the western part of Irian Jaya, which probably refers to *An. bancroftii*.[3] The adult, particularly if the scales are rubbed off, is often confused with *An bancroftii*.[4] If present, breeding places are usually in areas with lush vegetation and shade though this species has on occasion been found in sunny areas. It is found in clear water (rice fields), slowly running streams, ponds and swamps, in ditches, and in wells. Brackish water is usually avoided.

An. subpictus: The larvae are found in excavations, borrow pits, buffalo wallows, rice fields, drains, pools, furrows in gardens, water tanks, and other miscellaneous breeding places. It is largely indifferent to salinity and pollution, being found in water ranging from fresh to that containing 8.6% or more salt. The adult usually does not feed on man but may rest indoors.[4] Found near Misool and near the Biak airport. It is no longer reported in Biak, perhaps due to sanitation.[3]

An. karwari: The larvae breed in small streams, seepage water along streams, springs, and irrigation canals of rice fields. They may also be found in stagnant water. Adults have been found resting in houses as well as in animal shelters.[4] Once commonly found near Jayapura, it is very rare today, perhaps due to past indoor residual insecticide spraying.[3] Collections made in and near Jayapura, December 1973 to February 1974 failed to find *An. karwari*.[5]

An. farauti sensu lato: The taxonomic position of *Anopheles farauti* is complex. At least six different *Anopheles farauti*, that are morphologically indistinguishable (designated No 1 - 6) have been identified by electrophoretic techniques.[6] It is often the dominate species along coastal zones, though have been found as high as 2250 meters. It is widespread in the southern plain. The larvae breed in many types of natural or artificial water collections provided it is not shaded. In coastal regions it will breed in brackish water (up to 4.6% salt). Sweeney reported that *An. farauti* No 1. may be distinguished from *An. farauti* No. 2 and No. 3 by its ability to survive exposure to sea water.[7] It is also found in irrigation ditches, with or without marginal vegetation, large streams with grassy banks and floating wood. The adults are largely nocturnal and will feed indoors as well as outdoors. They will feed during the daylight if disturbed from their cool shaded resting areas.[4] Maffi et al. found only *An. farauti* larvae in the Jayapura/Sentani region, though the authors admitted that *An. koliensis* may have been present in the collection and misidentified due to the close similarity of *An. farauti* and *An koliensis* larvae in the early instars.[6] In the highlands, Jajawijaya Regency, larvae were identified as members of the *An. punctulatus* complex, so it is not possible to determine from this collection if one or more of the *An. punctulatus* complex predominates at the higher altitude.[6] Adult landing/biting collections made at Arso Kecamatan, located approximately 60 kilometers southeast of Jayapura, seldom revealed *An farauti* as a vector (NAMRU-2 annual reports, 1987-1989).

An. punctulatus: The larvae breed in open, sunny water collections, both natural and man-made. The water may be turbid or clear. Occasionally, pools in drying stream beds may be used, particularly when conditions are dry. Aquatic vegetation may or may not be present. The adult is nocturnal and generally prefers human blood. It is seldom found indoors, preferring to feed outdoors.[4] It is most common in the northern and western regions. Further inland in the north it sometimes predominates. It has also been recorded from the mountains of Vogelkop Peninsula and the west-central Mountains (Siriwo Valley). It has been found in large numbers in catching stations far from human habitation. In the south, *An. punctulatus* is of minor importance though it may dominate in a few inland localities.[3] Sporozoite positive rates reported by Burkot et al. ranged from 0% to 3.3% over a 25 month collection period. [8] During March 1986 landing collections from Kwamki and surrounding areas near Timika, southern Irian Jaya, resulted in a sporozoite positive rate of 1.75%. *An. punctulatus* made up less than 10% of all anophelines collected in Arso Kecamatan (NAMRU-2 annual reports 1987-1989).

An koliensis: The larvae of this species have been collected from temporary pools in grassland and in pools along the edge of jungles. They have also been frequently observed in water filled depressions along human and cattle trails, particularly if shaded for less than a quarter of the day (Church, unpublished observations). They prefer water exposed to sunlight rather than shaded conditions. They often are associated with *An. farauti* and in one locality were collected from the same water with *An. farauti* and *An. punctulatus*. The adults are strongly anthropophilic and have been found resting during the day in houses in greater numbers than any of the other local anophelines, often making up 90% of the catches .[9] It is known to occur at high altitudes on New Guinea, up to 1700 meters.[4] The species is widespread, occurring in the low lands as well as mountainous areas. It is widespread in the Waropen area (northern plain) and Meervlakte and may be the dominant species in several localities. They are less common in the southern plains.[3] Landing/ biting collections in Papua New Guinea over 25 months revealed a sporozoite positive rate from 0.2% - 3.8% .[8] In the Arso Kecamatan region sporozoite rates ranged from 0.4% - 5.0% during May -Dec 1994 (Church, unpublished data).

An. clowi: A rare species which was collected from an area near present day Jayapura.[3] A single larvae, from which the female type was described, was found in a road rut. Adults were captured in and near Jayapura. Van Hell (1952, official report, unpublished) mentions as breeding places: pools and ditches, in full sunshine.[4]

An. novaguinensis: Larvae were found in a small pool in a sago palm locality. In Australia, they have been found in clear, shallow, sunlit water with abundant algal growth. Females bite freely in the open at sundown and will enter buildings to feed.[4] This species has been collected from the middle reaches of Merauke River (southern plain).[3]

An. annulipes: The larvae are frequently found in ground pools of shallow depth, with or without suspended clay. It is common in rock pools in association with green algae. They may be found in sunlit or shaded locations. It has also been recorded from a wide variety of water sources including weedy rock-pools, running water alongside streams, gravel-beds, open sandy pools, swamp margins, hoof prints, wheel tracks, slit trenches, water holding rubbish, and brackish water up to 1.6% salinity. The female will feed readily on man in the open, near breeding sites. It also will enter and feed in huts and tents and will rest indoors during the day.[4] It is widespread in Australia and in Papua New Guinea. It may be present in the southern plain of Irian Jaya.[3]

An. incognitus: A species based on the collection of a single larval specimen.[10] A doubtful species, represented by a single larva found in the Merauke area (southern plain).[3] Largely unknown and may be a synonymy of *An. hilli*.[4]

An. hilli: Larvae are found in polluted or brackish water (up to 4.2% salinity) in both natural and man-made breeding places. They may also occur inland in muddy pools, slit trenches, and shallow weedy margins of fresh water swamps. Breeding places are usually in full sunlight, but may be found in areas that are partially shaded. The adults bite humans and are most active shortly after sunset. Fed females can be collected readily from houses and tents.[4] This species has been recorded only from the southern part of the province. It may be abundant during the wet season (March - April).[3]

An. meraukensis: The larvae were found in shallow pools in a swamp near Merauke. Some of the pools were old wheel-ruts with algae growth on the bottom, other larvae were found in shallow ditches, also with algal growth. The water was fresh and almost clear without any shade. Larvae were also found in flooded rice fields. The female was found indoors.[4] Known only from the Merauke-Kumbe strip.[3]

An. lungae: Considered rare, the larvae are almost always found in shaded locations, normally jungle seepage areas, along the margins of streams, potholes in dried stream beds, rock holes, dense jungle swamps and temporary pools, and in muddy hog wallows.[11] The water is usually clear and cool.[4] Larvae are often common, but difficult to collect because of their habit of resting in very shallow water on the margins of breeding places. Both larvae and pupae have been observed to crawl out of the water and rest on the bank or on dead leaves floating on the water.[4] A film of water always covers the larvae or pupae. Eighteen larvae were collected in a Sentani Lake village (Puai) but have not been detected since.[3]

An. longirostris: The larvae have been found in large jungle swamps, near river banks, overgrown back-waters, sago swamps, seepage pools, wheel tracks and pig wallows. It is not found in open country. It occurs either in the jungle or near its fringe preferring shade. Adults occasionally bite man, but primarily feed on marsupials. Evidence suggests that it takes no part in malaria transmission.[4] Burkot et al. examined over 3,000 *An. longirostris*, collected from landing collections in Papua New Guinea, without detecting sporozoites.[8] As a species they are widely distributed, but almost always collected in lower numbers than members of the punctulatus complex. In the south it may be the most prevalent species in some villages in Mimika, Asmat and Digul areas.[3]

An. annulatus: This species is only know from its type locality, the Upper Digul (southern plain).[3] Larvae were found in a small stream originating from a jungle swamp. No large trees were present.[4]

An. stigmaticus: This species is only known from a Anggi-gita, a mountain lake at about 5,800 feet in the eastern part of Vogelkop Peninsula.[3] It has been found in ditches with clear, very cold water with grassy banks at an altitude of 1860 meters.[4]

An. bancroftii: The larvae breed in the jungle in old cut-off courses of the Digul River where coarse reeds, algae and Azolla combine to give shade and shelter. In Australia, it breeds in shaded, swampy areas. The adults readily attack man indoors as well as in the open in New Guinea and northern Australia. It may dominate in many parts of the southern plains but is less common in other parts of Irian Jaya.[3]

An. papuensis: The larvae were collected at altitudes of approximately 6000 feet in two localities Minj, New Guinea and Al Valley, behind Nandugl, Central Highlands.[12] Larval habitat was described as being a semi-rock pool covered by a type of swamp cane (Minj) or a clear pool, 6-8 inches deep, partially covered by watercress and fallen sticks.[12] The second location was shaded by overhanging trees.[12]

An. pseudobarbirostris: This species breeds in the jungle, usually in clear pools with abundant aquatic vegetation, in dense shade or in places which may receive direct sunlight only during the middle of the day. In Sulawesi it was reported from sunlit pools.[13] Usually not found in great numbers.[4]

REVIEW OF THE VECTORIAL CAPACITY OF THE PUNCTULATUS COMPLEX

Bryan et al.[14] estimated that at least nine species occur in the punctulatus complex based on data from 14 isozyme systems. Foley et al.[6] identified six species in the punctulatus complex from 19 localities in Papua New Guinea; *Anopheles punctulatus sensu stricto*, *An. koliensis*, *An. farauti* No. 1, and three newly recognized species, *An. farauti* No. 4, No. 5, and No. 6. Foley et al.[15] recently reported on another member of the punctulatus complex which they designated as *Anopheles* sp. near *punctulatus*. *Anopheles clowi*, *An. farauti* No. 2 and No. 3, and *An. rennelensis* were not detected in Papua New Guinea. Isozyme patterns can be used to distinguish the sibling species.[15, 16] DNA probes have also been developed which may be used to identify members of the punctulatus complex.[17,18] The vectorial importance of each of the species collected in these studies have not been determined, but all were collected from human landing collections. The recognition of these species and inability to morphologically distinguish them based on the criteria given by Belkin add confusion to most past studies in New Guinea as species actually present in the study localities were not determined at the molecular level.[19, 20] In the discussion below, the use of the term punctulatus complex refers to identifications of *Anopheles farauti*, *Anopheles koliensis*, and *Anopheles punctulatus* with the understanding that more recent research has indicated a wide array of sibling species within the species complex.

Three members of the *Anopheles punctulatus* complex; *An. punctulatus*, *An. farauti* and *An. koliensis* are considered the most important vectors of malaria in Irian Jaya. The vectorial capacity of this complex has been well documented. In general, this complex is considered facultative exo- or endophagous and feeds where ever it finds a suitable host, be it inside a human habitation or outside. Slooff [21]proposed a new term, pantachophagous meaning "Gr.: πανταχου = everywhere, φαγειν = to feed)." reflecting the true habits of the complex. The resting sites are dependent on where it feeds.[21] In two study sites, Entrop, where DDT had been sprayed for approximately 8 years and Arso where spraying had never occurred, Slooff found that feeding activity in Arso occurred all night, but predominated between the hours of 2130 and 0330.[21] In contrast, *An. koliensis* feed predominately between the hours 1830 to 1930 in Entrop, presumably in response to DDT residual spraying. An interesting aspect of his work is that indoor collections were always greater than outdoor collections (3.6:1) in Arso as contrasted with collections in Entrop where the indoor:outdoor ratio was 1.15: 1; perhaps related to selection pressure by residual insecticides. In Arso Pir IV human landing collections made from 1994 - 1995 revealed that outdoor collections predominate for *An. koliensis* by a 1.59:1 ratio, perhaps in response to insecticide treated bed nets and residual wall spraying (Church, unpublished data). Slooff found the biting activity of *An. koliensis* in Kecamatan Arso increased dramatically when rain occurred following a period in which the favored breeding sites of *Anopheles koliensis* were scarce.[22] The author thought lack of breeding sites caused a delay in oviposition. Following an increase in acceptable breeding sites the mosquitoes oviposited and immediately sought another blood meal.

Slooff reported the preferred host of the punctulatus complex collected from Kecamatan Arso and Entrop was man, but cautioned that this may be misleading because of the scarcity of alternate blood meal sources in those study areas. Indeed, he further stated that "huge population densities of *A. farauti* and *A. koliensis* in the uninhabited Meervlakte and of *A. punctulatus* in the Siriwo Valley, suggest that all these species can do very well without man." [21] In one locality of Papua New Guinea, where alternate sources of blood meals coexist with man, the preferred host for *An. koliensis* and *An. punctulatus* was dog followed by man and for *An. farauti*, pig followed by man.[23] All three species commonly feed on more than one host per blood meal (different species or same species). Based on ABO blood markers with mother-daughter pairs, approximately 13% of blood fed anophelines captured indoors had fed on both mother and daughter.[24] In addition to the above information, Burkot et al.[8] reported on the average number of sporozoites found in infective *An. koliensis*, *An. punctulatus*, and *An. farauti*. The average number of *Plasmodium falciparum* sporozoites was 6, 230 for all three mosquito species and did not significantly differ between species. With *P. vivax*, significantly more sporozoites were found in *An. punctulatus* than in *An. farauti* or *An. koliensis.* The arithmetic mean number of sporozoites were 1,050; 330; and 250, respectively. It was not clear if the *P. vivax* sporozoite densities reported for *An. punctulatus* were a function of increased sporozoite production per oocyst or of heavier oocyst infections in the areas where *An. punctulatus* was the predominate vector.

Longevity of *An. punctulatus*, was evaluated by Charlwood et al.[25] and Charlwood and Bryan.[26] They calculated the daily survival rate as 0.75 and 0.77, respectively during a mark-recapture experiment in Papua New Guinea. Using the above values approximately 2/100 *An. punctulatus* would survive long enough to transmit *P. falciparum* malaria and 1/18 would survive long enough to transmit *P. vivax* assuming that the first blood meal was infectious to the mosquito. This is obviously an over estimate of vector potential since many of the mosquitoes will fail to obtain an infective blood meal on the first feed. Since oviposition is estimated to occur every 2.9 - 3.7 days,[25, 26] each blood meal that failed to result in an infection would increase by 2.9 to 3.7 days the required time span the mosquito had prior to becoming infective. During periods when a suitable oviposition site is not available, the length of time between oviposition and blood meals will be longer.

MALARIA CONTROL STRATEGIES

Kitron wrote an excellent review article on malaria control where he focused, not on why so many projects failed, but why a few enjoyed long term success.[27] The author stated that there was no single measure sufficient to control malaria and that future anti-malaria programs must adopt strategies that are flexible, integrated into local health services, and coordinated with agricultural practices. In addition, a certain threshold of socioeconomic development, health services infrastructure, and educational level may have to be reached for the successful application and sustainability of anti-malarial measures. A horizontal approach was strongly advocated with coordination between public health and agriculture practices. He suggested several direct control strategies centered around the incorporation of permanent source reduction of breeding sites and chemical larviciding as a secondary approach. Primary demographic factors include: political, economy of a country or region, socioeconomic factors, demographic and migration practices, and health service infrastructure. Organizations and institutions involved with control efforts, as well as cost and funding sources also come into play. Because indirect factors operate simultaneously with direct control efforts, the relative contributions of different components are difficult to ascertain.

Agricultural practices are often important in determining the occurrence and extent of mosquito breeding places and therefore influence mosquito larvae and adult density. Animal husbandry practices can contribute to the degree of malaria transmission depending on the zoophilic characteristics of the *Anopheles* vector. Agriculture also influences the human population in the framework of socioeconomic and demographic factors, such as housing, nutrition, migration, and urbanization. The level of education is of extreme importance, especially in contributing to the effectiveness of disseminated information on malaria and its control as well as the degree of community participation in conducting control work. Three examples of successful control programs were given. They all took place in countries where standards of living were rapidly improving (Palestine, USA, and Italy) and malaria was seasonal (unstable). The following characteristics were shared by each example:

flexibility in methods, thorough knowledge of vector bionomics, reliance of permanent breeding site elimination (source reduction), larval control, education, and propaganda of information.

Following the split of Palestine, Israel underwent a period of extensive agricultural development. Malaria cases dropped rapidly. The Anti-malarial Division had responsibility for all direct control activities and was represented in government organizations that oversaw agricultural settlements, water development projects, drainage work, use of insecticides, etc. Israel remains free of indigenous malaria despite the presence of anopheline vectors and the continuing influx of refugees with malaria from outside areas. This is due in large part to continuing surveillance, anti-larval activities, intense agricultural development of nearly all available land, and careful management of water resources. Literacy rates are high and sanitation (running water and sanitary facilities) are available in nearly all settlements. Interestingly, residual spraying of walls with insecticides and active case detection was rare. In all fairness, it should be stated that none of this occurred before the arrival of an efficient authority (the British government in 1919). "Community participation and the ideological fervor of the Jewish immigrants were major components of malaria control around the Jewish settlements."[27]

Italy's malaria control program, like those before, relied heavily on elimination of breeding sites with quinine as an adjunct to treat reservoirs of infection. Malaria remained high until the late 1920s when larviciding was combined with breeding source reduction and quinine was dropped from the control strategy. Larviciding, and large scale projects that eliminated many breeding sites greatly reduced the number of malaria cases in Italy. When World War II intervened malaria control efforts were drastically curtailed. At the end of the war many outbreaks occurred following seasonal flooding, the result of general neglect of active control work. Between 1944-1945 anti-malarial activities near Naples proved very successful. The use of DDT was expanded to other areas of Italy and malaria ceased to be a problem by the 1950s. It should be noted that the success of DDT followed extensive water management projects and a concentrated effort to reduce anopheline breeding sites. From a historical point of view, Italy's success with DDT served as a model for the WHO global anti-malarial campaign. Many countries are still trying to wean themselves from the idea that residual spraying of insecticides is the answer to malaria eradication despite the fact that WHO gave up the global eradication program in 1969.

Gunawan reviewed the background of malaria control in Irian Jaya through 1980.[28] Before 1954, malaria control consisted of larviciding with oil, limited drainage of breeding sites, and provision of chemoprophylaxis for the non-indigenous population.[29] DDT and dieldrin were first used in field trials during 1954 in Irian Jaya.[30] Because of promising results in the Sentani area, residual DDT applications were expanded to include the coverage of houses for 80,000 people by the end of 1955.[30] The five-year Dutch campaign of DDT residual spraying and two years of mass drug administration with chloroquine and pyrimethamine resulted in a considerable decrease in malaria transmission in Irian Jaya, but eradication could not be achieved.[31] During the 60s and 70s the malaria control program fell on hard times and residual spraying was rarely done.[28] During 1979 residual applications with DDT were resumed with coverage of approximately 32,000 households.[28] During 1979 and 1980 parasite rates declined in most areas except Genyem (Nimboran district); however, the decline in the adjacent areas Sentani, Jayapura, and Abepura were not convincing. Unfortunately the annual parasite surveys revealed another trend, the percentage of *P. falciparum* cases had increased. Transmission was still significant, infant parasite rates ranged from 0.6 to 29.6%, excluding Biak. The program Gunawan described was typical of vertical control programs in which community participation was passive voluntary compliance of DDT residual wall spraying.[28] This trend of vertical control continues today in the transmigration areas of Irian Jaya. Treated bed nets are distributed and walls are treated with a residual insecticide without community involvement. In Arso PIR IV, despite receiving bed nets and residual wall treatment, malaria prevalence was 39% during May 1994.

There is little doubt that bed nets can reduce morbidity and mortality in an immune population;[32] however, the advantages of bed nets for a nonimmune population are equivocal. Bed nets potentially reduce the number of infective bites a person receives. While a person may still become infected, there is a correlation between the number of infective bites and severity of the disease as measured by parasitemia levels and clinical symptoms in immune populations.[33] It is unknown if this correlation exists in a nonimmune population. This is particularly relevant in the transmigration villages because of the near universal nonimmune status of the immigrants. Charlwood and Graves[34] reported on the effect of permethrin impregnated bed nets on a population of *Anopheles farauti* and *An. koliensis*. They found that following the introduction of treated bed nets that *An. farauti* biting rates per man-night dropped from 689 per night pre-treatment to 483 post-treatment; however, survival rates were not significantly effected. The population of *An. koliensis* was dropping before treatment of bed nets, but even after bed nets were treated the number of young mosquitoes remained constant with a possible reduction on survivorship. Interestingly, they reported a shift in biting distribution for both *An. farauti* and *An. koliensis;* peak biting activity shifted from post midnight peak to a pre-midnight peak. Taylor reported a similar trend with the same vector (*An. farauti* No. 1) after walls were treated with DDT in the Solomon Islands.[35] This trend was not observed with *Anopheles punctulatus* and permethrin treated bed nets in Malaita Province, Solomon Islands, though a cyclone and relocation of village housing interfered with the interpretation of the results.[36] The two former studies highlight the difficulty of control measures that rely solely on insecticides. First, insufficient coverage may fail to stop transmission and secondly, the insecticide may alter behavior so that the mosquito feeds earlier in the night when fewer people are protected by bed nets. This type of vertical control is contrasted by Schuurkamp et al.[37] who reported on the reduction in malaria parasite rates and splenomegaly following DDT residual spraying in a group of villages in Papua New Guinea. DDT was only part of an organized vector control program initiated by Ok Tedi Mining Limited in March 1982 at Tabubil and associated construction sites and camps and in the villages in 1983. Village houses were sprayed with DDT twice per year. Source reduction of breeding sites and larviciding with Abate (temephos) were occasionally done in some local villages together with ULV fogging operations. It is difficult to ascribe what factors of vector control and the medical program contributed to the success in significantly reducing the malaria parasite rates and splenomegaly. There was a paucity of entomological information during the study from 1982 -1986 with only one mosquito collection period in June of 1986. Ok Tedi is typical of many malaria control projects where a combination of increased economic development, medical infrastructure, and coordinated vector control efforts (source reduction, larviciding, DDT residual spraying and relocation of villages to more favorable (less malarious areas) result in a significant reduction in malaria prevalence. As a model for other control operations it may be inferred that success was the result of many factors and that its implementation at other sites may be disappointing because of different locality, social economic factors and financial support.

The question remains, how might the lessons learned from successful programs be applied to Irian Jaya. Taking each point Kitron mentioned as contributing to the long term success of a malaria control program let us speculate how this might be applied.[27] **Flexibility and thorough knowledge of the vector population**. Flexibility is the ability to quickly tailor a response to a changing requirement. Thorough knowledge of the vector population is dependent on basic field research into the behavior and vectorial capacity of a vector, plus routine surveillance to identify times when direct intervention is best applied to reduce the transmission of disease. In Arso the basic research on vector dynamics is largely done, but there is no current surveillance program which would predict when control measures are needed. Current control programs rely on a mandated schedule of residual spraying and distribution of bed nets in the transmigration areas which may or may not occur during critical periods of disease transmission. **Education.** The people who are moved from populated areas of Java and Bali and re-settled in Irian Jaya are generally unfamiliar with malaria and associated risk factors. In a survey of one of the transmigration villages, approximately 325 people (one adult from each household) were asked about their knowledge of malaria. No respondent knew that mosquitoes transmitted malaria (unpublished data, Arso PIR IV, 1994). Community participation is stated as an absolute requirement for malaria control programs if they are to be sustainable over time without the direct infusion of massive amounts of money and technical expertise from outside agencies. Yet the community will not participate if it does not understand why they are participating or sense the need. A malaria education curriculum, incorporated into the elementary schools, would serve to educate the public in the long term, particularly in light of Indonesia's progressive program of mandatory education through SMP. Community participation would also make **permanent larval control** programs feasible. Identification of breeding sites and elimination of the sites can only occur if the community participates, because these programs are often labor intensive and require continual maintenance.

Agricultural practices can also have a profound effect on human behavior and vector populations. The clearing of jungle for agriculture and subsequent human settlements results in exposure to sunshine and innumerable small holes which fill with water, the preferred breeding site of the punctulatus complex. Even after the land becomes cultivated, care must be taken to prevent the establishment of breeding sites. Pastures that are over grazed become muddy and provide breeding sites that would not be present if adequate grass were present. Poor drainage of rice fields can also provide breeding sites. All of this can be overcome, but once again it is a matter of education. **Public health officials and agricultural officials** must coordinate activities and provide feasible recommendations to the villagers that will result in agricultural practices that provide both high quality crops and reductions in the vector populations. Last, but certainly not least, the **local health care provider** must become an integral part of a village's malaria control program. The provider must be able to educate those patients that contract malaria on preventive measures they can take. He must be knowledgeable in personal protective measures (bed nets, repellents), breeding site elimination, and human behavior modification, so that the patient can reduce his/her chances of contracting malaria in the future.

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